

Fig. 1
(Prior Art)

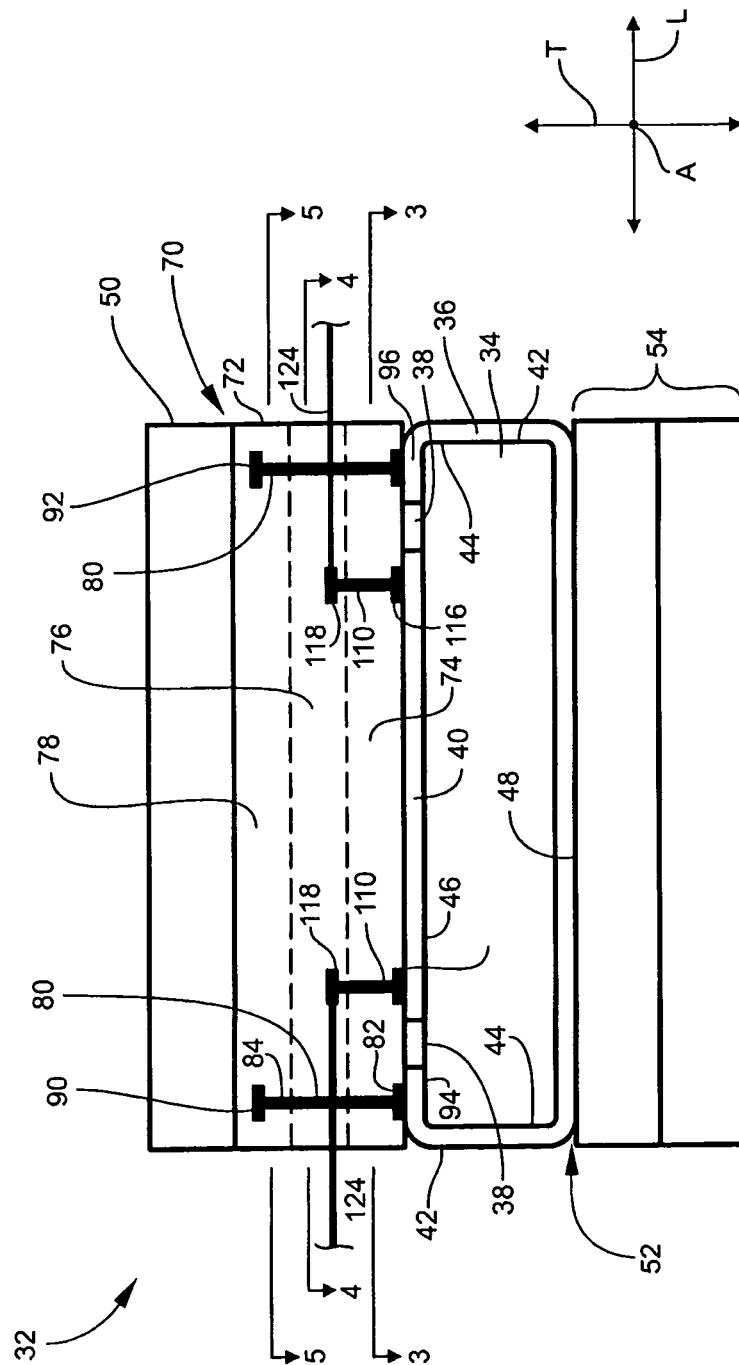


Fig. 2

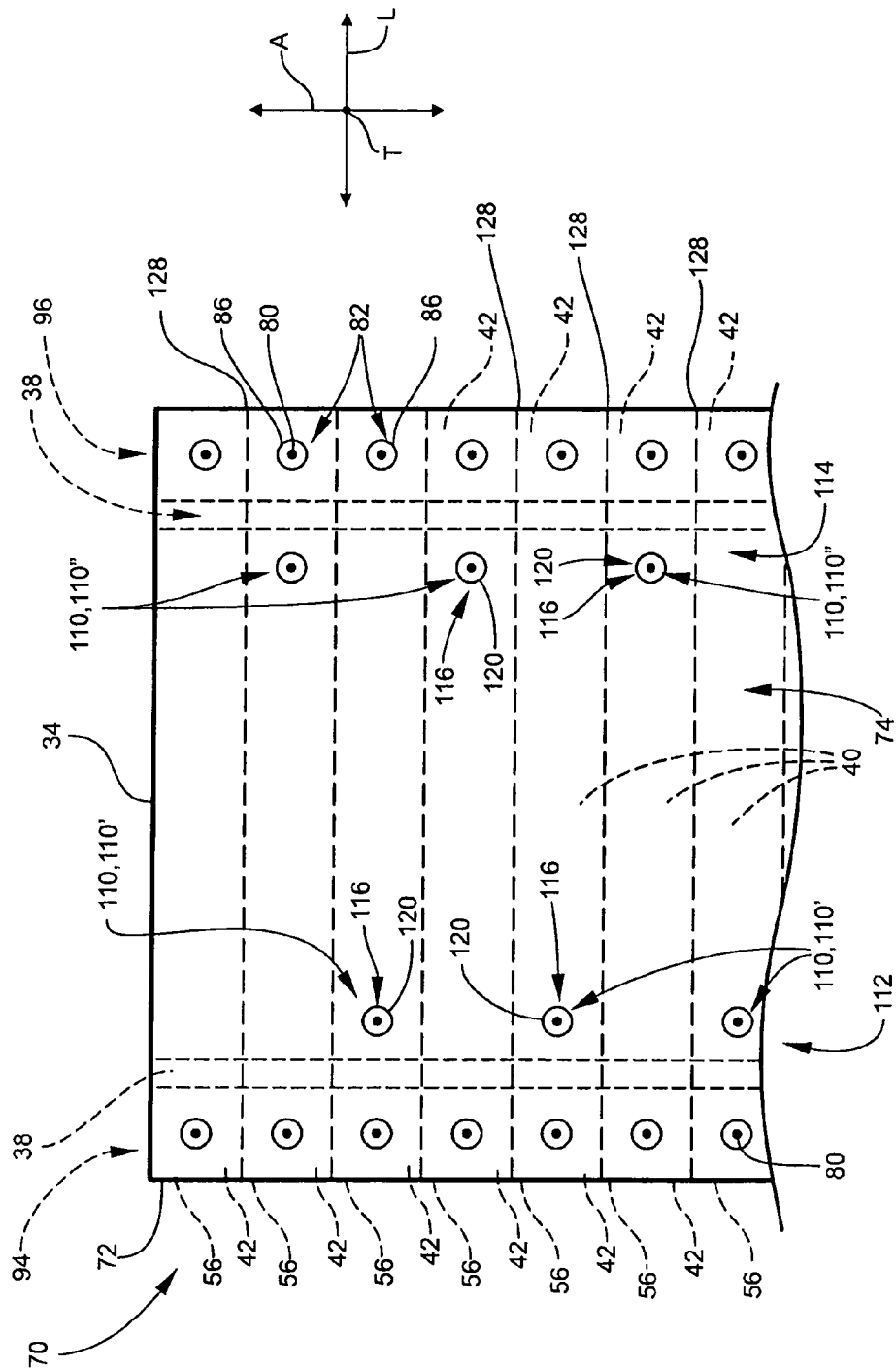


Fig. 3

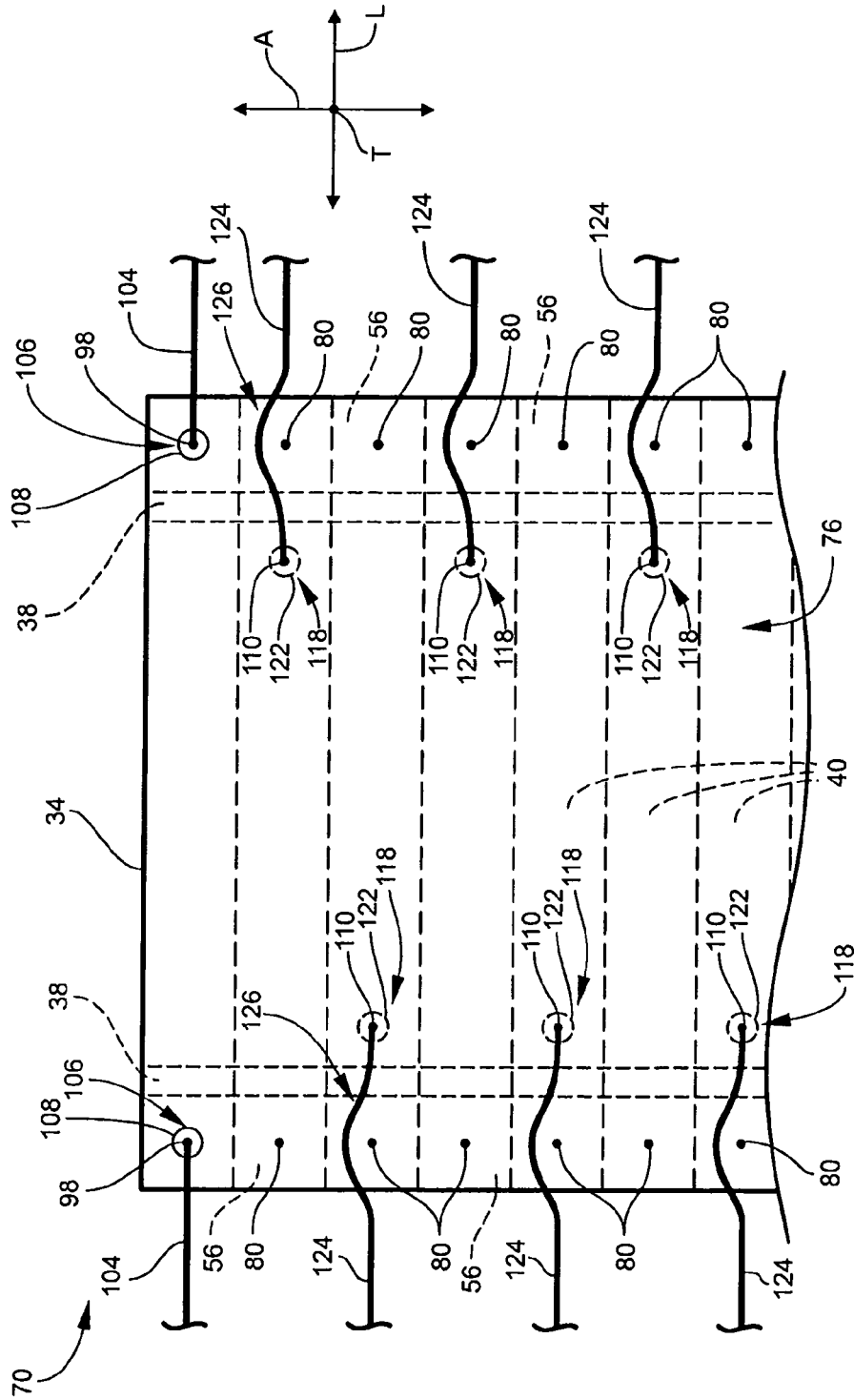


Fig. 4

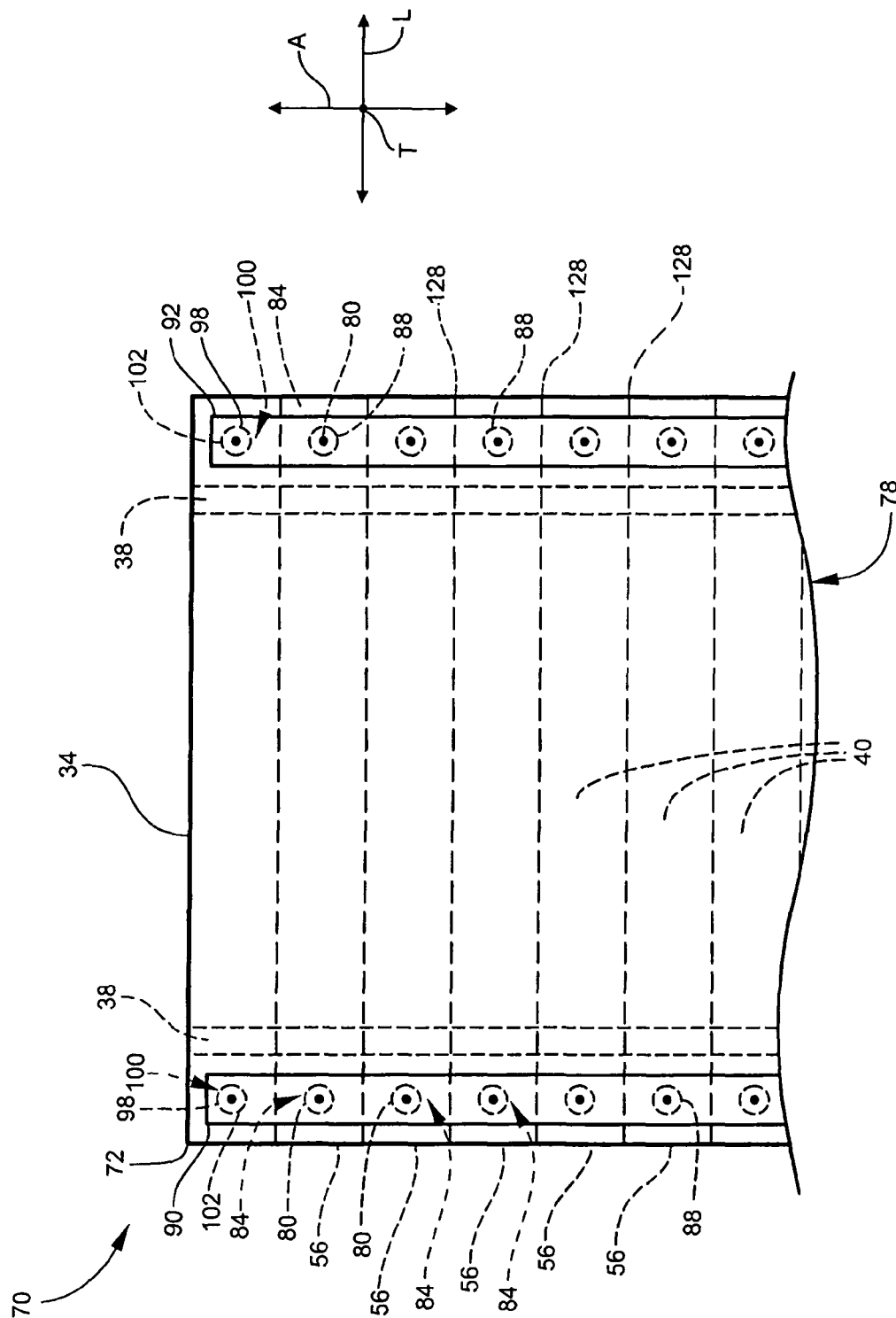


Fig. 5

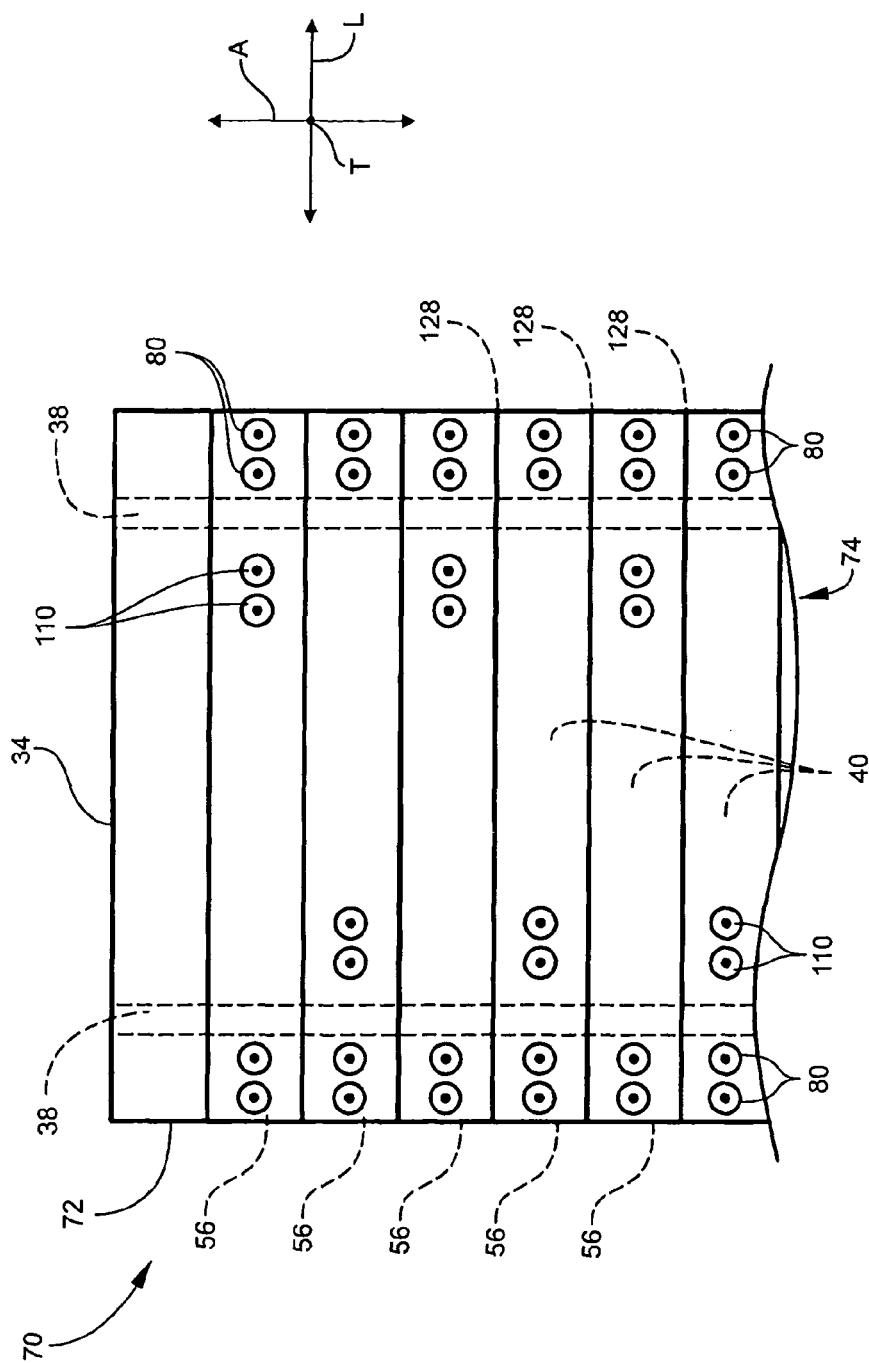


Fig. 6

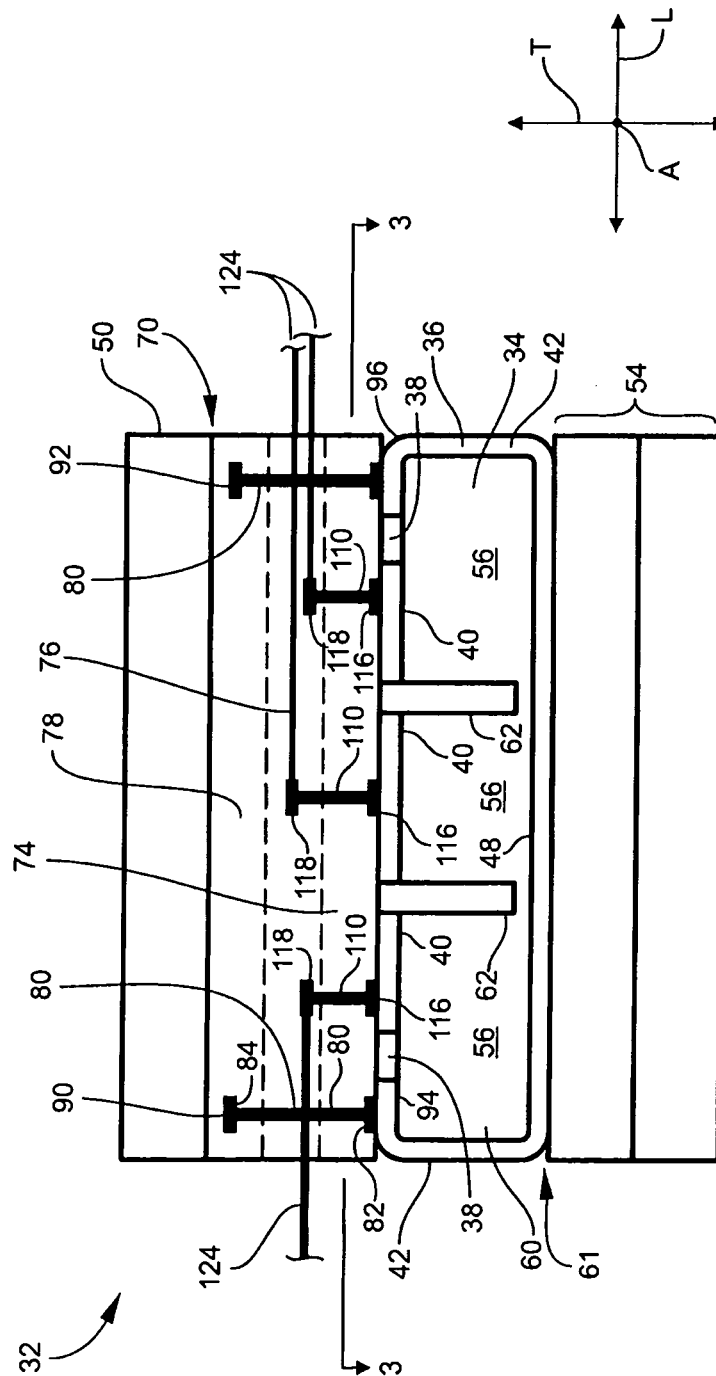


Fig. 7

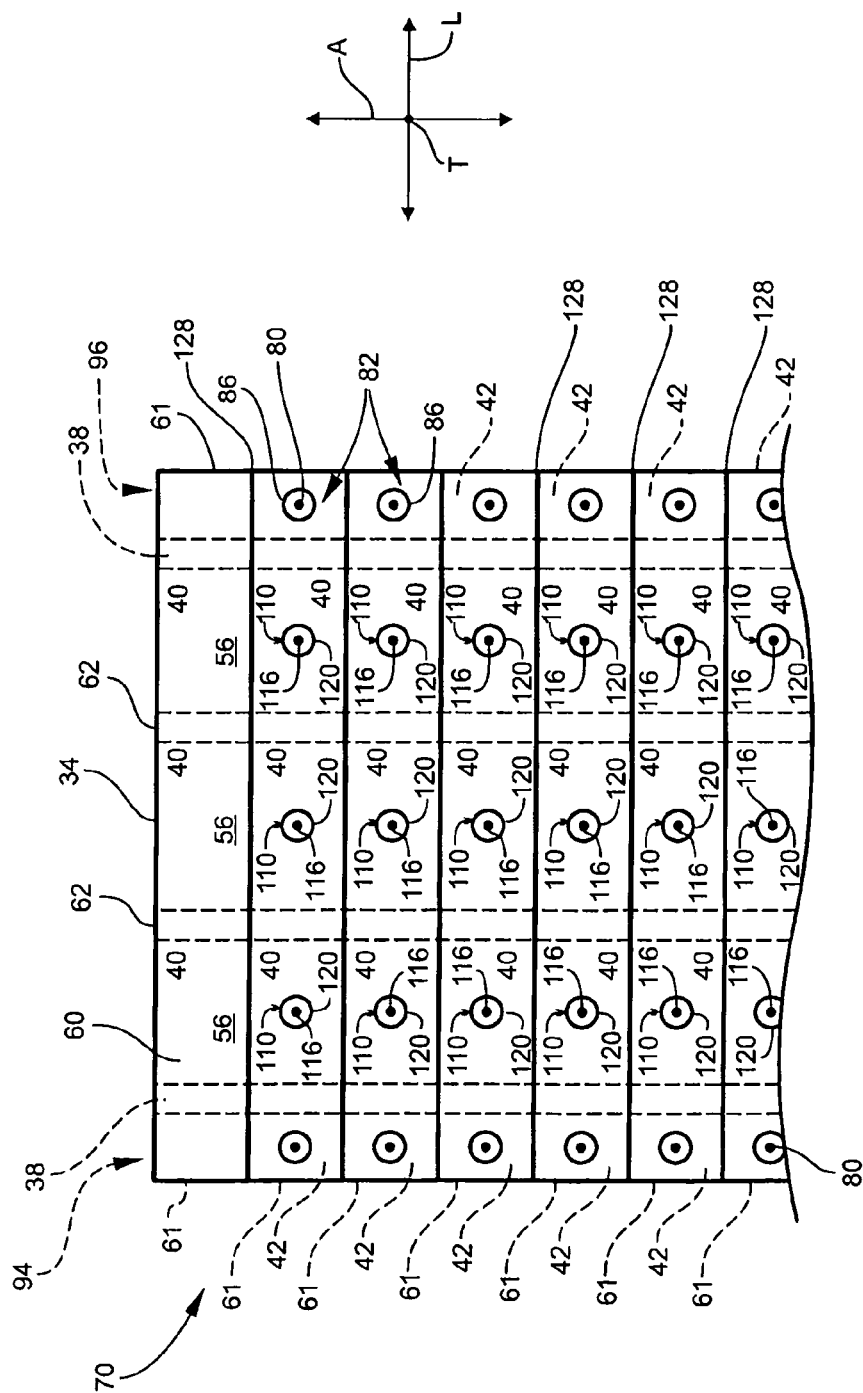


Fig. 8

1

ULTRASONIC ARRAY TRANSDUCER, ASSOCIATED CIRCUIT AND METHODS OF MAKING THE SAME

RELATED APPLICATION DATA

The present application is a national stage application under 35 U.S.C. 371 of International Application No. PCT/US2011/044818 filed 21 Jul. 2011, which is a continuation-in-part of U.S. patent application Ser. No. 12/841,165, filed Jul. 21, 2010, now U.S. Pat. No. 8,299,687, which are each hereby incorporated by reference in their entirety.

FIELD

Embodiments relate in general to transducers and, more particularly, to ultrasonic array transducers.

BACKGROUND

There are a number of ways in which an ultrasonic transducer can be made. One manufacturing approach will be described in connection with FIG. 1. A monolithic block of piezoelectric ceramic material **10** is provided. A portion of the piezoelectric material **10** is covered by a plating material **12** wrapped therearound. Deactivation cuts **14** are made along a top surface of the plating material **12** to define a positive electrode **16** and a ground electrode **18**. The deactivation cuts **14** extend into and out of the page in FIG. 1. The positive electrode **16** is formed by that portion of the plating material **12** located between the two deactivation cuts **14**. The ground electrode **18** is formed by the plating material **12** outside of the two deactivation cuts **14**. With the use of a wrap around plating material **12**, electrical connections to the positive and ground electrodes **16**, **18** can be easily made on the same surface of the piezoelectric material **10**. The block of piezoelectric ceramic material **10** and the plating material **12** with the deactivation cuts **14** form a piezoelectric material/electrode assembly **24**.

A flexible circuit **22** is disposed on the top of the piezoelectric material/electrode assembly **24**. Electrical connections are made between individual traces of the flexible circuit **22** and the positive and ground electrodes **16**, **18** in locations of each intended transducer element. For instance, wires can be soldered onto the positive and ground electrodes **16**, **18** and attached to individual traces of the flexible circuit **22**. A solid backer **26** is bonded to the top side of the piezoelectric material/electrode assembly **24** with the flexible circuit **22** sandwiched therebetween. One or more matching layers **28** are then attached to the bottom side of the piezoelectric material/electrode assembly **24**.

A plurality of individual transducer elements are formed using a dicing saw **30** to make a plurality of parallel dices or cuts in the assembly. The dicing saw **30** is brought into contact with the assembly from the patient side of the assembly, that is, from the matching layer **28** side of the assembly. Thus, the dicing saw **30** cuts through the one or more matching layers **28**, through the plating material **12**, through the piezoelectric material **10**, through the flexible circuit **22** and into a portion of the backer **26**. A plurality of transducer elements are developed by the dicing operation. The cuts formed by the dicing saw **30** can extend in a direction that is perpendicular to the direction in which the deactivation cuts **14** extend.

The undiced portion of the backer **26** holds the diced assembly together. After the dicing operation, kerf filler can be placed in the cuts to provide structural support to the diced

2

assembly. The kerf filler can also provide some degree of acoustic isolation between the transducer elements.

However, when dices are made in the assembly, the common ground electrode **18** is severed, and a plurality of individual ground electrodes is formed. The individual ground electrodes must be reconnected. Typically, a wire is soldered across the individual ground electrodes to reconnect the ground electrodes. This process is labor intensive and time consuming. Further, the heat from the soldering process can depolarize the piezoelectric material **10**, thereby adversely affecting the performance of the transducer.

SUMMARY

In one aspect, circuits for transducer element arrays are described herein which, in some embodiments, may assist in mitigating one or more disadvantages associated with individual ground electrode reconnection. In some embodiments, circuits described herein are flexible circuits. In some embodiments, a circuit described herein comprises a first layer for receiving a transducer element array, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias corresponding to transducer elements of the array, the first vias extending through the first layer to the at least one ground and comprising first ends for receiving ground electrodes of the transducer elements and second ends electrically connected to the ground.

In some embodiments, the ground layer comprises a plurality of grounds for interfacing with ground electrodes of transducer elements through the first vias. In being disposed over the first layer, the ground layer, in some embodiments, is adjacent to the first layer. Alternatively, in some embodiments, one or more additional layers are disposed between the first layer and the ground layer. In some embodiments wherein one or more additional layers are disposed between the first layer and the ground layer, the first vias extend through the first layer and the one or more additional layers to the ground(s) of the ground layer.

Moreover, in some embodiments, a circuit described further herein comprises one or more ground vias for electrically connecting one or more grounds of the ground layer to an external circuit, such as that of an ultrasound system. In some embodiments, a ground via extends through the ground layer to the exterior of the circuit. In some embodiments, for example, a ground via extends laterally out of the ground layer. In some embodiments, a ground via extends into one or more layers adjacent to the ground layer.

A circuit described herein, in some embodiments, further comprises second vias corresponding to transducer elements of the array, the second vias extending through the first layer and comprising first ends for receiving positive electrodes of the transducer elements and second ends electrically connected to traces in electrical communication with circuitry external to the circuit, such as that of an ultrasound system. In some embodiments, at least some of the second vias terminate in one or more additional layers disposed between the first layer and the ground layer. In some embodiments, at least some of the second vias terminate in one or more additional layers disposed over the ground layer. In some embodiments, at least some of the second vias terminate in the ground layer. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of second vias.

In another aspect, ultrasonic transducer systems are described herein. In some embodiments, an ultrasonic transducer system comprises an array comprising a plurality of transducer elements, the transducer elements comprising

3

individual positive electrodes and ground electrodes and a circuit coupled to the array, the circuit comprising a first layer for receiving the array, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias corresponding to transducer elements of the array, the first vias extending through the first layer to the at least one ground and comprising first ends electrically connected to individual ground electrodes of the transducer elements and second ends electrically connected to the ground of the ground layer.

In some embodiments, a circuit of an ultrasonic transducer system described herein further comprises one or more ground vias for electrically connecting one or more grounds of the ground layer to an external circuit, such as that of an ultrasound system. In some embodiments, a ground via extends through the ground layer to the exterior of the circuit. In some embodiments, for example, a ground via extends laterally out of the ground layer. Moreover, in some embodiments, a ground via extends into one or more layers adjacent to the ground layer.

A circuit of an ultrasonic transducer system, in some embodiments, further comprises second vias corresponding to transducer elements of the array, the second vias extending through the first layer and comprising first ends electrically connected to positive electrodes of the transducer elements and second ends electrically connected to one or more traces in electrical communication with an ultrasound system. In some embodiments, at least one second via is associated with a positive electrode of each transducer element of the array.

In some embodiments, at least some of the second vias terminate in one or more additional layers disposed between the first layer and the ground layer of the circuit. In some embodiments, at least some of the second vias terminate in one or more additional layers disposed over the ground layer. In some embodiments, at least some of the second vias terminate in the ground layer. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of second vias.

As illustrated in the Figures of the present application, an ultrasonic transducer system described herein can have an associated axial direction A, a longitudinal direction L that is transverse to the axial direction A, and a thickness direction T. In some embodiments, a transducer element array of an ultrasonic transducer system described herein comprises a piezoelectric material separated into N transducer elements in the axial direction to provide an N×1 array. In some embodiments, a transducer element array of an ultrasonic transducer system comprises a piezoelectric material separated into N transducer groups in the axial direction and M transducer elements in the longitudinal direction transverse to the axial direction to provide an N×M array. In some embodiments, a transducer element array of an ultrasonic transducer system described herein is a curved array. In some embodiments, a transducer element array of an ultrasonic transducer system described herein is a planar array.

In another aspect, methods of making transducer assemblies are described herein. In some embodiments, a method of making a transducer assembly comprises providing a piezoelectric element partially covered with a plating material defining a ground electrode and at least one positive electrode and providing a circuit comprising a first layer for receiving the piezoelectric element, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias extending through the first layer to the at least one ground and comprising first ends for receiving the ground electrode of the piezoelectric element and second ends electrically connected to the at least one ground. The first layer of the circuit is interfaced with the piezoelectric element and the first ends

4

of the first vias are placed in electrical communication with the ground electrode of the piezoelectric element. A plurality of cuts are made in the piezoelectric element having a depth passing through the piezoelectric element, plating material and first layer of the circuit and terminating prior to reaching the ground of the ground layer. The cuts provide separated transducer elements in the axial direction, the transducer elements comprising individual ground electrodes and positive electrodes, wherein the individual ground electrodes are connected to one another through the first vias in electrical communication with the at least one ground, thereby obviating the need to reconnect the ground electrodes with further processing subsequent to the dicing operation.

In some embodiments of methods of making a transducer assembly described herein, the piezoelectric element is provided with a plurality of cuts in the axial direction, the cuts terminating prior to the ground electrode on the opposing side of the piezoelectric element and providing M separated transducer elements in the longitudinal direction transverse to the axial direction. In some embodiments wherein the piezoelectric element is provided with M separated transducer elements in the longitudinal direction, the cuts made in the piezoelectric element having a depth passing through the piezoelectric element, plating material and first layer of the circuit and terminating prior to reaching the ground of the ground layer, provide in the axial direction N separated groups of the M transducer elements, thereby providing an N×M array.

These and other embodiments are described in greater detail in the detailed description which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a prior art method of making an ultrasonic transducer system.

FIG. 2 is a side elevation cross-sectional view of a transducer system according to one embodiment described herein.

FIG. 3 is a top plan cross-sectional view of a first layer of one embodiment of a circuit described herein, viewed along line 3-3 in FIG. 2.

FIG. 4 is a top plan cross-sectional view of at least one additional layer of one embodiment of a circuit described herein, viewed along line 4-4 in FIG. 2.

FIG. 5 is a top plan cross-sectional view of a ground layer of one embodiment of a circuit described herein, viewed along line 5-5 in FIG. 2.

FIG. 6 is a top plan cross-sectional of a first layer of one embodiment of a circuit described herein, showing an arrangement in which vias are provided in pairs.

FIG. 7 is a side elevation cross-sectional view of a transducer system according to one embodiment described herein.

FIG. 8 is a top plan cross-sectional view of a first layer of an embodiment of a circuit described herein, viewed along line 3-3 in FIG. 7.

DETAILED DESCRIPTION

Embodiments described herein can be understood more readily by reference to the following detailed description and examples and their previous and following descriptions. Elements, apparatus and methods described herein, however, are not limited to the specific embodiments presented in the detailed description and examples. It should be recognized that these embodiments are merely illustrative of the principles of the present invention. Numerous modifications and adaptations will be readily apparent to those of skill in the art without departing from the spirit and scope of the invention.

5

In one aspect, circuits for transducer element arrays are described herein. In some embodiments, circuits described herein are flexible circuits. In some embodiments, circuits for transducer element arrays described herein permit facile connection of ground electrodes of transducer elements formed by one or more dicing operations.

In some embodiments, a circuit described herein comprises a first layer for receiving a transducer element array, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias corresponding to transducer elements of the array, the first vias extending through the first layer to the at least one ground and comprising first ends for receiving ground electrodes of the transducer elements and second ends electrically connected to the ground.

The term "via" denotes a construction comprising an accessway through one or more layers of a circuit described herein, the accessway comprising any suitable element for establishing electrical connection between electrically conducting elements within different layers of the circuit and/or with one or more electrical conductors external to the circuit. In some embodiments, the vias can be pads with plated holes, which can be made to be conductive by electroplating, or the holes can be filled with annular rings or rivets. Embodiments described herein are not limited to any particular type of via.

In some embodiments, a circuit described herein further comprises one or more ground vias for electrically connecting one or more grounds of the ground layer to an external circuit, such as that of an ultrasound system. In some embodiments, a ground via extends through the ground layer to the exterior of the circuit. In some embodiments, for example, a ground via extends laterally out of the ground layer. In some embodiments, a ground via extends into one or more layers adjacent to the ground layer.

A circuit described herein, in some embodiments, further comprises second vias corresponding to transducer elements of the array, the second vias extending through the first layer and comprising first ends electrically coupled to positive electrodes of the transducer elements and second ends electrically connected to one or more traces in electrical communication with circuitry external to the circuit, such as that of an ultrasound system. In some embodiments, at least one second via is associated with a positive electrode of each transducer element of the array.

In some embodiments, at least some of the second vias terminate in one or more additional layers disposed between the first layer and the ground layer of the circuit. In some embodiments, at least some of the second vias terminate in one or more additional layers disposed over the ground layer. In some embodiments, at least some of the second vias terminate in the ground layer. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of second vias.

In some embodiments, layers of a circuit described herein can be constructed from any desired material not inconsistent with the objectives of the present invention. In some embodiments, layers of a circuit described herein are constructed of flexible materials to provide a flexible circuit. In some embodiments, layers of a circuit described herein comprise one or more flexible dielectric polymeric materials. In some embodiments, a suitable flexible dielectric polymeric material comprises one or more polyimides. In some embodiments, for example, one or more layers of a circuit described herein comprise KAPTON® polyimide commercially available from DuPont of Wilmington, Del. Alternatively, in some embodiments, layers of a circuit described herein are constructed of one or more rigid or semi-rigid dielectric polymeric materials.

6

In some embodiments, a circuit described herein is suitable for interfacing with a transducer element array comprising a piezoelectric material separated into N transducer elements in the axial direction to provide an N×1 array. In some embodiments, N is 64 or a multiple of 64. In some embodiments, for example, N is 128, 192, 256, 320, 384, 448 or 512. In some embodiments, N is 96.

In some embodiments, a circuit described herein is suitable for interfacing with a transducer element array comprising a piezoelectric material separated into N transducer groups in the axial direction and M transducer elements in the longitudinal direction transverse to the axial direction to provide an N×M array. In some embodiments, N of an N×M array is 64 or a multiple of 64, including 128, 192, 256, 320, 384, 448 or 512. In some embodiments, N of an N×M array is greater than 512. In some embodiments, N of an N×M array described herein is 96. Moreover, in some embodiments M of an N×M array is selected from the group consisting of 3, 5, 7, 9 and 11. In some embodiments, a circuit described herein is suitable for interfacing with a transducer element array having an N×M construction according to Table I.

TABLE I

Transducer Arrays N × M Transducer Array
64 × 1, 3, 5, 7, 9 or 11
96 × 1, 3, 5, 7, 9 or 11
128 × 1, 3, 5, 7, 9 or 11
192 × 1, 3, 5, 7, 9 or 11
256 × 1, 3, 5, 7, 9 or 11
320 × 1, 3, 5, 7, 9 or 11
384 × 1, 3, 5, 7, 9 or 11
448 × 1, 3, 5, 7, 9 or 11
512 × 1, 3, 5, 7, 9 or 11

In some embodiments, a transducer element array interfacing with a circuit described herein is a curved array. In some embodiments, a transducer element array interfacing with a circuit described herein is a tightly curved array. In some embodiments, a circuit described herein is suitable for interfacing with a curved array or tightly curved array having any transducer element arrangement provided in Table I herein. In some embodiments, for example, a circuit described herein is suitable for interfacing with a curved array or a tightly curved array having transducer element arrangement of 192×5 or 256×5.

In some embodiments, a transducer element array of an ultrasonic transducer system described herein is a planar array.

In another aspect, ultrasonic transducer systems are described herein. In some embodiments, an ultrasonic transducer system comprises an array comprising a plurality of transducer elements, the transducer elements comprising individual positive electrodes and ground electrodes and a circuit coupled to the array, the circuit comprising a first layer for receiving the array, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias corresponding to transducer elements of the array, the first vias extending through the first layer to the at least one ground and comprising first ends electrically connected to individual ground electrodes of the transducer elements and second ends electrically connected to the ground of the ground layer. In some embodiments, a circuit of an ultrasonic transducer system described herein further comprises one or more ground vias for electrically connecting one or more grounds of the ground layer to an external circuit, such as that of an ultrasound system.

7

A circuit of an ultrasonic transducer system, in some embodiments, further comprises second vias corresponding to transducer elements of the array, the second vias extending through the first layer and comprising first ends electrically connected to positive electrodes of the transducer elements and second ends electrically connected to one or more traces in electrical communication with an ultrasound system. In some embodiments, at least one second via is associated with a positive electrode of each transducer element of the array.

In some embodiments, at least some of the second vias terminate in one or more additional layers disposed between the first layer and the ground layer of the circuit. In some embodiments, at least some of the second vias terminate in one or more additional layers disposed over the ground layer. In some embodiments, at least some of the second vias terminate in the ground layer. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of second vias.

In some embodiments, a transducer element array of an ultrasonic transducer system comprises a piezoelectric material separated into N transducer elements in the axial direction to provide an N×1 array. In some embodiments, a transducer element array of an ultrasonic transducer system comprises a piezoelectric material separated into N transducer groups in the axial direction and M transducer elements in the longitudinal direction transverse to the axial direction to provide an N×M array.

In some embodiments, a transducer element array of an ultrasonic transducer system described herein is a curved array. In some embodiments, a transducer element array of an ultrasonic system described herein is a tightly curved array. In some embodiments, a transducer element array of an ultrasonic transducer system described herein is a planar array. In some embodiments, a transducer element array of an ultrasonic transducer system has a transducer element arrangement selected from the arrangements provided in Table I.

FIG. 2 is a side elevation cross-sectional view of an ultrasonic transducer system according to one embodiment described herein. The ultrasonic transducer system 32 of FIG. 2 comprises an N×1 transducer element array 34 comprising a plurality of transducer elements 56, the transducer elements comprising a piezoelectric ceramic material. As FIG. 2 is a side elevation cross-sectional view of the transducer system 32, the cross-section of a single transducer element 56 of the array 34 in conjunction with the section of the circuit 70 associated with the transducer element 56 is shown. The remaining transducer elements 56 of the array 34 and associated circuitry 70 having a similar construction extend along the axial direction. The transducer element 56 comprises an electrically conductive plating material 36 wrapped therearound. The plating material 36 is discontinuous at regions 38 to define a positive electrode 40 and ground electrode 42 of the transducer element 56. Discontinuous regions 38 can be formed by a variety of processes including making deactivation cuts to remove the plating material 36 or etching the plating material 36 chemically and/or lithographically. In some embodiments, discontinuous regions 38 are provided by selectively depositing the plating material 36 on the transducer element 56. Selective deposition of the plating material 36, in some embodiments, is achieved by masking and/or other lithographic techniques, chemical etching and/or ion etching techniques.

The ground electrode 42 can extend about a portion of an upper side 46 of the transducer element 56, over side walls 44 and across a lower side 48 of the transducer element 56. The terms “upper” and “lower” are used for convenience to facilitate the discussion and are not meant to be limiting. Addition-

8

ally, one or more acoustic matching layers 54 are coupled to one side of the transducer element array 34.

The ultrasonic transducer system 32 of FIG. 2 also comprises a circuit 70 interfaced with the transducer element array 34. As with the transducer element array 34, the circuit 70 has an associated axial direction A, a longitudinal direction L that is transverse to the axial direction A, and a thickness direction T.

In the embodiment of FIG. 2, the circuit 70 comprises a first layer 74 for receiving or interfacing with the transducer element array 34 and a ground layer 78 over the first layer 74, the ground layer comprising a first ground 90 and a second ground 92. Although two grounds 90, 92 are illustrated in the embodiment of FIG. 2, circuits comprising a single ground or more than two grounds in the ground layer are contemplated herein. At least one additional layer 76 is disposed between the first layer 74 and the ground layer 78. In the embodiment of FIG. 2, a backer 50 is coupled to the circuit 70 and can provide structural rigidity to the circuit 70.

In some embodiments, at least one of the first 90 and second 92 grounds is provided on an exterior surface of the ground layer 78, as opposed to within the ground layer 78. In some embodiments, for example, at least one of the first 90 and second 92 grounds is disposed on the exterior surface of the ground layer 78 interfacing with the at least one additional layer 76. In some embodiments, at least one of the first 90 and second 92 grounds is disposed on the exterior surface of the ground layer interfacing with the backer 50.

The circuit 70 comprises first vias 80 extending through the first layer 74 and the at least one additional layer 76 to the first 90 and second 92 grounds of the ground layer 78. The first vias 80 comprise first ends 82 electrically connected to the ground electrode 42 of transducer elements 56 of the array 34 and second ends 84 electrically connected to the first 90 or second ground 92. Although two first vias 80 and two grounds 90, 92 are illustrated in FIG. 2, embodiments described herein contemplate use of a single via 80 in the circuit 70 to electrically connect the ground electrode 42 of transducer element 56 to a single ground 90 of the ground layer 78.

Moreover, in the embodiment illustrated in FIG. 2, first vias 80 extend in a vertical direction normal to layers of the circuit 70. In some embodiments, first vias 80 can extend at one or more angles non-normal to layers of the circuit 70. In some embodiments, first vias 80 can extend laterally through one more layers of the circuit 70 in addition to vertically.

The circuit 70 illustrated in FIG. 2 further comprises second vias 110 extending through the first layer 74. The second vias 110 comprise first ends 116 electrically connected to the positive electrode 40 of the transducer element 56. The second vias 110 terminate in the at least one additional layer 76, and the second ends 118 of the second vias are electrically connected to conductors or traces 124 in electrical communication with external circuitry, such as that of an ultrasound system. As described herein, the second vias can pass through the first layer and terminate in any layer over the first layer. In the embodiment of FIG. 2, for example, the first vias 110 can also terminate in the ground layer 78. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of the second vias.

In the embodiment of FIG. 2, the conductors or traces 124 extend in the longitudinal direction (L) of the circuit 70 to the exterior of the at least one additional layer 76 where the traces 124 can be electrically connected to external circuitry, such as that of an ultrasound system. Although two second vias 110 are illustrated in FIG. 2, embodiments described herein contemplate use of a single second via 110 in the circuit 70 to

electrically connect the positive electrode **40** to external circuitry through one or more conductors or traces **124**.

FIG. 3 is a top plan cross-sectional view of the first layer **74** of the circuit **70** of FIG. 2 viewed along line 3-3 in FIG. 2. Individual transducer elements **56** of the N×1 transducer element array **34** defined by cuts **128** in the longitudinal direction of the piezoelectric ceramic material would be occluded by the first layer **74** in the presently illustrated view but are shown for reference purposes. Similarly, ground electrodes **42**, positive electrodes **40** and discontinuous regions **38** would also be occluded by the first layer **74**, but are shown for reference purposes.

A plurality of first vias **80** can extend through the first layer **74**, through the at least one additional layer **76** and into the ground layer **78**. The plurality of first vias **80** can be formed in the circuit **70** such that each of the first vias **80** can be outboard of the discontinuous regions **38**. In other words, each of the plurality of first vias **80** can be aligned with a respective one of the ground electrodes **42** of the transducer elements **56** when the circuit **70** is disposed on the transducer element array **34**, as shown in FIG. 3.

In some embodiments, there can be at least two first vias **80** associated with each transducer element **56**. For example, one of the first vias **80** can be associated with a first longitudinal end portion **94** of the ground electrode **42**, and another one of the first vias **80** can be associated with a second longitudinal end portion **96** of the ground electrode **42**. The first vias **80** can be substantially aligned in the axial direction A along the first and second longitudinal end portions **94**, **96** of the ground electrodes **42**, as is shown in FIG. 3. While not shown in FIG. 3, one or more of the first vias **80** can be offset from the other first vias **80** in the axial direction A.

As in FIG. 2, each of the plurality of first vias **80** can have a first end **82** and a second end **84**. The first ends **82** of the first vias **80** can be adapted to facilitate operative connection to the ground electrodes **42** of the transducer elements **56**. In some embodiments, for example, the first ends **82** of the first vias **80** can include connection pads **86**. The second ends **84** of the first vias **80** can terminate within or external to the ground layer **78**. The second ends **84** of the first vias **80** can be adapted to facilitate operative connection to one or more of grounds in the ground layer **78**. In some embodiments, for example, the second ends **84** of the first vias **80** can include connection pads.

FIG. 5 is a top plan cross-sectional view of the ground layer **78** of the circuit **70** of FIG. 2, as viewed in the direction of the arrows associated with line 5-5 in FIG. 2. Individual transducer elements **56** of the N×1 transducer element array **34** defined by cuts **128** in the longitudinal direction of the piezoelectric ceramic material would be occluded by the ground layer **78** in the presently illustrated view but are shown for reference purposes. Similarly, discontinuous regions **38** in the plating material **36** would also be occluded by the ground layer **78**, but are shown for reference purposes.

The ground layer **78** can include one or more different traces, including, for example, a first ground **90** and a second ground **92**. The first and second grounds **90**, **92** can provide a common return path for signals in the circuit **70**. The first and second grounds **90**, **92** can be elongated continuous conductors. The first and second grounds **90**, **92** can be made of any suitable material and have any desired shape not inconsistent with the objectives of the present invention. In some embodiments, the first and second grounds **90**, **92** can be substantially parallel to each other. The first and second grounds **90**, **92**, in some embodiments, can extend in generally the axial direction A. As described herein, the second ends **84** of the first vias **80** can be operatively connected to a respective one of the

grounds **90**, **92**. The term “operatively connected,” as used herein, can include direct and indirect connections.

Some of the plurality of first vias **80** can be united at the first ground **90**, and some of the plurality of first vias **80** can be united at the second ground **92**. The first and second grounds **90**, **92** can be taken outside the circuit **70**. To that end, there can be a ground via **98** associated with each of the grounds **90**, **92**. The ground vias **98** are different from the first vias **80**. For instance, as will be explained in more detail below, the first vias **80** operatively connect the ground electrodes **42** of individual transducer elements **56** to a respective one of the grounds **90**, **92** whereas the ground vias **98** operatively connect at least one of the grounds **90**, **92** to a conductor extending outside of the circuit **70**.

A ground via **98** can be operatively connected at a first end **100** to a respective ground **90**, **92**. The first end **100** may include a connection pad **102** or other suitable structure to facilitate operative connection. In some embodiments, a ground via **98** can extend from the ground layer **78** and into at least one additional layer **76** disposed between the ground layer **78** and the first layer **74**. Alternatively, in some embodiments, a ground via **98** can extend laterally or vertically out of the ground layer **78**.

FIG. 4 is a top plan cross-sectional view of the at least one additional layer **76** of the circuit **70** of FIG. 2, as viewed in the direction of the arrows associated with line 4-4 in FIG. 2. Individual transducer elements **56** of the N×1 transducer element array **34** defined by cuts **128** in the longitudinal direction of the piezoelectric ceramic material would be occluded by the at least one additional layer **76** in the presently illustrated view but are shown for reference purposes. Similarly, discontinuous regions **38** in the plating material **36** would also be occluded by the first layer **74**, but are shown for reference purposes.

The at least one additional layer **76** of the circuit **70** comprises ground vias **98** extending therein from the ground layer **78** as described herein. The ground vias **98** are operable to connect grounds **90**, **92** (not shown) of the ground layer **78** to an external circuit, such as that of an ultrasound system. In the at least one additional layer **76**, a conductor **104** can be operatively connected to a second end **106** of the ground via **98**. The second end **106** may include a connection pad **108** or other suitable structure to facilitate operative connection. The conductor **104** can extend generally in the longitudinal direction L to outside the circuit **70**. The conductor **104** can be operatively connected to a cable assembly (not shown) that can carry electrical signals to an ultrasound system (not shown).

The circuit **70** can include a plurality of second vias **110**. In the non-limiting embodiments illustrated in FIGS. 2-5 herein, the plurality of second vias **110** extend from the first layer **74** of the circuit **70** and into a depth of the at least one additional layer **76**. The plurality of second vias **110** can be provided such that each second via **110** can be aligned with a positive electrode of respective one of the transducer elements **56**. In some embodiments, for example, the second vias **110** are inboard of the discontinuous regions **38**. Thus, each of the second vias **110** can be in line with a respective one of the positive electrodes **40** the transducer elements **56** when the circuit **70** is interfaced with the transducer element array **34**.

The plurality of second vias **110** can be distributed in any suitable manner not inconsistent with the objectives of the present invention. In some embodiments, the second vias **110** can be provided in a staggered arrangement, the staggered arrangement comprising a first subset **110'** of the second vias **110** alternating with a second subset **110''** of the second vias **110**, as is shown in FIG. 3. Each of the second vias **110** in the

11

first subset 110' can be provided proximate to a first longitudinal end 112 of the positive electrode 40 of a respective one of the transducer elements 56. Each of the second vias 110 in the second subset 110" can be provided proximate to a second longitudinal end 114 of the positive electrode 40 of a respective one of the transducer elements 56. Such a staggered arrangement can be convenient for avoiding overcrowding of individual traces from the circuit 70. Moreover, as described herein, second vias 110 can be terminated in different layers of the circuit 70 to mitigate or avoid overcrowding.

However, embodiments are not limited to an arrangement in which the plurality of second vias 110 is staggered. For instance, the second plurality of vias 110 can be substantially aligned in the axial direction A. Thus, it will be appreciated that the plurality of second vias 110 can be provided in any suitable location and arranged in any suitable manner with respect to the transducer elements 56.

As illustrated in FIGS. 2-4, each of the second vias 110 can have a first end 116 and a second end 118. The first ends 116 of the second vias 110 are operable to receive positive electrodes 40 of individual transducer elements 56. The first ends 116 of the plurality of second vias 110 can include connection pads 120 (FIG. 3) and/or other features to facilitate operative connection to another item, such as one of the positive electrodes 40 of the transducer elements 56.

In the embodiment of FIG. 4, the second ends 118 of the second vias 110 terminate within the at least one additional layer 76. The second ends 118 of the second vias can include connection pads 122 and/or other features to facilitate operative connection to another item. In some embodiments, conductors or traces 124 can be operatively connected to second ends 118 of the second vias 110. The conductors or traces 124 can extend generally in the longitudinal direction L within the second layer 76. In some embodiments, one or more conductors or traces 124 can include a jog portion 126 that extends around the first via 80 on the same transducer element 56 to prevent electrical shorting. The jog portion 126 can have any suitable configuration so long as the conductor 124 avoids contact with the first vias 80. The conductors or traces 124 can be operatively connected to a cable assembly (not shown) that can carry electrical signals to an ultrasound system (not shown).

In some embodiments, it may be beneficial to configure the first, second and/or ground vias to minimize problems that would be caused if one or more of the vias 80, 98, 110 were to break or malfunction. For example, redundancy can be introduced into the system so that additional vias are provided in at least some locations. To that end, at least some of the vias 80, 98 and/or 110 can be provided in pairs or in triplets. An example of an arrangement in which pairs of vias are provided is shown in FIG. 6.

As described herein, in some embodiments, a transducer element array of an ultrasonic transducer system comprises a piezoelectric material separated into N transducer groups in the axial direction and M transducer elements in the longitudinal direction transverse to the axial direction to provide an N×M array.

FIG. 7 illustrates a side elevation cross-sectional view of a transducer system according to one embodiment described herein. The ultrasonic transducer system 32 of FIG. 8 comprises an N×M transducer element array 34. The transducer element array 34 comprises a piezoelectric ceramic material 60 separated into N transducer element groups 61 in the axial direction and M transducer elements 56 in the longitudinal direction transverse to the axial direction to provide the N×M array. As FIG. 7 is a side cross-sectional view of the transducer system 32, the cross-section of a single transducer

12

element group 61 comprising M=3 transducer elements 56 in the longitudinal direction of the array 34 in conjunction with the section of circuitry 70 associated with the transducer elements 56 is shown. The remaining transducer element groups 61 of the array 34 and associated circuitry 70 having similar construction extend along the axial direction.

The piezoelectric ceramic material 60 of the transducer element array 34 comprises an electrically conducting plating material 36 wrapped therearound. A plurality of cuts 62 are provided in the plating material 36 and the piezoelectric ceramic material 60 to define 3 transducer elements 56 in the longitudinal direction of the single axial transducer group 61 illustrated. In the embodiment of FIG. 7, the cuts do not pass through the plating material 36 on the opposing or lower side 48 of the piezoelectric ceramic material. Moreover, the plating material 36 is discontinuous at regions 38. The cuts 62 in the plating material 36 in conjunction with the discontinuous regions 38 define positive electrodes 40 for the M=3 transducer elements 56 of the axial transducer group 61.

The remaining portion of the plating material 61 defines a ground electrode 42 for each of the M=3 transducer elements 56. The ground electrode 42 can extend about a portion of an upper side of the transducer group 61, over side walls and across a lower side 48 of the transducer group 61.

Alternatively, in some embodiments, the plating material 36 is selectively deposited on regions of the piezoelectric ceramic material 60 between the cuts 62 to define the positive electrodes 40 and the ground electrode 42 of the transducer elements 56. Selective deposition of the plating material 36, in some embodiments, is achieved by masking and/or other lithographic, chemical etching or ion etching techniques.

The ultrasonic transducer system 32 of FIG. 7 also comprises a circuit 70 interfaced with the transducer element array 34. As with the transducer element array 34, the circuit 70 has an associated axial direction A, a longitudinal direction L that is transverse to the axial direction A and thickness direction T.

In the embodiment of FIG. 7, the circuit 70 comprises a first layer 74 for receiving or interfacing with the transducer element array 34 and a ground layer 78 over the first layer 74, the ground layer comprising a first ground 90 and a second ground 92. Although two grounds 90, 92 are illustrated in the embodiment of FIG. 7, circuits comprising a single ground or more than two grounds in the ground layer are contemplated herein. At least one additional layer 76 is disposed between the first layer 74 and the ground layer 78. In the embodiment of FIG. 7, a backer 50 is coupled to the circuit 70 and can provide structural rigidity to the circuit 70.

In some embodiments, at least one of the first and second grounds is provided on an exterior surface of the ground layer 78, as opposed to within the ground layer 78. In some embodiments, for example, at least one of the first 90 and second 92 grounds is disposed on the exterior surface of the ground layer 78 interfacing with the at least one additional layer 76. In some embodiments, at least one of the first 90 and second 92 grounds is disposed on the exterior surface of the ground layer interfacing with the backer 50.

The circuit 70 comprises first vias 80 extending through the first layer 74 and the at least one additional layer 76 to the first 90 and second 92 grounds of the ground layer 78. The first vias 80 comprise first ends 82 electrically connected to the ground electrode 42 of the transducer elements 56 of the transducer group 61 and second ends 84 electrically connected to the first 90 and second grounds 92. Although two first vias 80 and two grounds 90, 92 are illustrated in FIG. 7, embodiments described herein contemplate use of a single

13

first via **80** in the circuit **70** to electrically connect the ground electrode **42** of transducer elements **56** to a single ground **90** of the ground layer **78**.

Moreover, in the embodiment illustrated in FIG. 7, first vias **80** extend in a vertical direction normal to layers of the circuit **70**. In some embodiments, first vias **80** can extend at one or more angles non-normal to layers of the circuit **70**. In some embodiments, first vias **80** can extend laterally through one more layers of the circuit **70** in addition to vertically.

The circuit **70** illustrated in FIG. 7 further comprises second vias **110** extending through the first layer **74**. The second vias **110** comprise first ends **116** electrically connected to the positive electrode **40** of each of the transducer elements **56** of the transducer group **61**. The second vias **110** terminate in the at least one additional layer **76**, and the second ends **118** of the second vias are electrically connected to conductors or traces **124** in electrical communication with external circuitry, such as that of an ultrasound system. As described herein, the second vias can pass through the first layer and terminate in any layer over the first layer. In the embodiment of FIG. 7, for example, the first vias **110** can also terminate in the ground layer **78**. In some embodiments, a first number of second vias terminate in a different layer of the circuit than a second number of the second vias to inhibit or prevent overcrowding.

In the embodiment of FIG. 7, the conductors or traces **124** extend in the longitudinal direction (L) of the circuit **70** to the exterior of the at least one additional layer **76** where the traces **124** can be electrically connected to external circuitry, such as that of an ultrasound system.

FIG. 8 is a top plan cross-sectional view of the first layer **74** of the circuit **70** of FIG. 7 viewed along line 3-3 in FIG. 7. Individual transducer groups **61** of the N×M transducer element array **34** defined by cuts **128** in the longitudinal direction of the piezoelectric ceramic material **60** would be occluded by the first layer **74** in the presently illustrated view but are shown for reference purposes. Similarly, the M=3 transducer elements **56** of each transducer group **61** defined by cuts **62** and the associated ground **42** and positive electrodes **40** would also be occluded by the first layer **74**, but are shown for reference purposes.

A plurality of first vias **80** can extend through the first layer **74**, through the at least one additional layer **76** and into the ground layer **78** (not shown). The plurality of first vias **80** can be formed in the circuit **70** such that each of the first vias **80** can be outboard of the discontinuous regions **38**. In other words, each of the plurality of first vias **80** can be aligned with a respective one of the ground electrodes **42** of the transducer elements **56** when the circuit **70** is disposed on the transducer element array **34**, as shown in FIG. 8.

In some embodiments, there can be at least two first vias **80** associated with each ground electrode **42** of the transducer element group **61**. For example, one of the first vias **80** can be associated with a first longitudinal end portion **94** of the ground electrode **42**, and another one of the first vias **80** can be associated with a second longitudinal end portion **96** of the ground electrode **42**. The first vias **80** can be substantially aligned in the axial direction A along the first and second longitudinal end portions **94**, **96** of the ground electrodes **42**, as is shown in FIG. 8. While not shown in FIG. 8, one or more of the first vias **80** can be offset from the other first vias **80** in the axial direction A.

As in FIG. 7, each of the plurality of first vias **80** can have a first end **82** and a second end **84**. The first ends **82** of the first vias **80** can be adapted to facilitate operative connection to the ground electrodes **42** of the transducer groups **61**. In some embodiments, for example, the first ends **82** of the first vias **80** can include connection pads **86**. The second ends **84** of the

14

first vias **80** can terminate within or external to the ground layer **78**. The second ends **84** of the first vias **80** can be adapted to facilitate operative connection to one or more of grounds in the ground layer **78**. In some embodiments, for example, the second ends **84** of the first vias **80** can include connection pads.

The circuit **70** further comprises a plurality of second vias **110**. As illustrated in FIGS. 7-8, the second vias **110** are aligned with the positive electrodes **40** of the M=3 transducer elements **56** of the transducer element groups **61**. The second vias comprise first ends **116** electrically connected to the positive electrodes **40** of the transducer elements **56**. Moreover, in the embodiment illustrated in FIG. 8, the second vias **110** comprise connection pads and/or other structures **120** operable to facilitate electrical connection with the positive electrodes **40** of the transducer elements **56**.

The circuit **70** can include a plurality of second vias **110**. In the non-limiting embodiments illustrated in FIGS. 2-8 herein, the plurality of second vias **110** extend from the first layer **74** of the circuit **70** and into a depth in the at least one additional layer **76**. The plurality of second vias **110** can be provided such that each second via **110** can be aligned with a positive electrode of respective one of the transducer elements **56**. In some embodiments, for example, the second vias **110** are inboard of the discontinuous regions **38**. Thus, each of the second vias **110** can be in line with a respective one of the positive electrodes **40** of the transducer elements **56** when the circuit **70** is interfaced with the transducer element array **34**.

In another aspect, methods of making transducer assemblies are described herein. In some embodiments, a method of making a transducer assembly comprises providing a piezoelectric element partially covered with a plating material defining a ground electrode and at least one positive electrode and providing a circuit comprising a first layer for receiving the piezoelectric element, a ground layer comprising at least one ground disposed over the first layer and a plurality of first vias extending through the first layer to the at least one ground and comprising first ends for receiving the ground electrode of the piezoelectric element and second ends electrically connected to the at least one ground. The first layer of the circuit is interfaced with the piezoelectric element and the first ends of the first vias are placed in electrical communication with the ground electrode of the piezoelectric element. A plurality of cuts are made in the piezoelectric element having a depth passing through the piezoelectric element, plating material and first layer of the circuit and terminating prior to reaching the ground of the ground layer. The cuts provide separated transducer elements in the axial direction, the transducer elements comprising individual ground electrodes and positive electrodes, wherein the individual ground electrodes are connected to one another through the first vias in electrical communication with the at least one ground of the ground layer, thereby obviating the need to reconnect the ground electrodes with further processing subsequent to the dicing operation.

In some embodiments of methods of making a transducer assembly, the piezoelectric element is provided with a plurality of cuts in the axial direction, the cuts terminating prior to the ground electrode on the opposing side of the piezoelectric element and providing M separated transducer elements in the longitudinal direction transverse to the axial direction. In some embodiments wherein the piezoelectric element is provided with M separated transducer elements in the longitudinal direction, the cuts made in the piezoelectric element having a depth passing through the piezoelectric element, plating material and first layer of the circuit and terminating prior to reaching the ground of the ground layer, provide in the axial direction N separated groups of the M transducer elements.

15

In some embodiments of methods of making a transducer assembly, a circuit described herein is fabricated independently from the piezoelectric element comprising the plating material and subsequently interfaced with the piezoelectric element. In some embodiments of methods of making a transducer assembly, a circuit described herein is interfaced with the piezoelectric element comprising the plating material by fabricating the circuit directly on the piezoelectric element.

A non-limiting example of a method of making a transducer assembly described herein is now provided with reference to FIGS. 2-5. A piezoelectric ceramic material comprising electrically conductive plating material and discontinuous regions 38 defining a positive electrode 40 and ground electrode 42 can be formed in any suitable manner. Additionally, one or more matching layers 54 can be attached to one side of the piezoelectric ceramic material in any suitable manner. In some embodiments, the matching layers 54 can improve acoustic energy transmission efficiency

A circuit 70 is interfaced with the side of the piezoelectric ceramic material comprising discontinuous regions 38. The first ends 82 of the first vias 80 of the circuit 70 can be operatively connected to the ground electrode 42 of the piezoelectric ceramic material in any suitable manner. For instance, the first end 82 of each first via 80 can be operatively connected to the ground electrode 42 by epoxy or other suitable adhesive and/or by physical engagement between the first vias 80 and the ground electrode 42.

Moreover, the first ends 116 of the second vias 110 can be operatively connected to the positive electrode 40 of the piezoelectric ceramic material. In some embodiments, a backer 50 operable to provide structural integrity to the transducer system 32 is attached to the circuit 70.

Individual transducer elements 56 are formed from the piezoelectric ceramic material by making a plurality of parallel dices or cuts 128 in the transducer assembly 32, as shown in FIGS. 2-4. Such cuts can be formed using a dicing saw (not shown) or other suitable cutting device. The dicing saw can be brought into contact with the assembly from the patient side of the assembly 32, that is, from the matching layer 54 side of the assembly. Thus, the dicing saw can cut through the one or more matching layers 54, through the plating material 36, through the piezoelectric material 34, and into the circuit 70. The dicing saw can penetrate the first and at least one additional layers 74, 76 of the circuit 70, terminating prior to the grounds 90, 92 of the ground layer 78. After the dicing operation, kerf filler (not shown) can be placed in the cuts 128 to provide structural support to the diced assembly.

Significantly, as the cuts terminate prior to the grounds 90, 92 of the ground layer 78 of the circuit 70, a common ground connection by way of the grounds 90, 92 is maintained between the newly formed transducer elements 56 having individual or discrete ground electrodes 42. Therefore, in some embodiments, no subsequent operation of reconnecting separated ground electrodes 42 of the transducer elements 56 is required.

Various embodiments of the invention have been described in fulfillment of the various objects of the invention. It should be recognized that these embodiments are merely illustrative

16

of the principles of the present invention. Numerous modifications and adaptations thereof will be readily apparent to those skilled in the art without departing from the spirit and scope of the invention.

That which is claimed is:

1. An ultrasonic transducer system comprising:

an array comprising a plurality of piezoelectric transducer elements, the piezoelectric transducer elements comprising individual positive electrodes and individual ground electrodes; and

a circuit coupled to the array, the circuit comprising a first layer for receiving the array, a layer comprising at least one ground disposed above the first layer and a plurality of first vias corresponding to piezoelectric transducer elements of the array, the first vias extending through the first layer to the at least one ground and comprising first ends electrically connected to the individual ground electrodes of the piezoelectric transducer elements and second ends electrically connected to the ground.

2. The ultrasonic transducer system of claim 1, wherein the circuit further comprises second vias corresponding to piezoelectric transducer elements of the array, the second vias extending through the first layer and comprising first ends electrically coupled to positive electrodes of the piezoelectric transducer elements and second ends electrically connected to one or more traces in electrical communication with circuitry external to the circuit.

3. The ultrasonic transducer system of claim 2, wherein at least one second via is associated with each piezoelectric transducer element of the array.

4. The ultrasonic transducer system of claim 1, wherein at least one first via is associated with each piezoelectric transducer element of the array.

5. The ultrasonic transducer system of claim 1, wherein the array comprises N transducer groups in an axial direction with each group comprising M piezoelectric transducer elements.

6. The ultrasonic transducer system of claim 5, wherein N is selected from the group consisting of 64, 96, 128, 192, 256, 320, 384, 448 and 512 and M is selected from the group consisting of 1, 3, 5, 7, 9 and 11.

7. The ultrasonic transducer system of claim 5, wherein at least one first via is provided for each of the N transducer groups of the array, the first end of the first via electrically connected to a ground electrode for the M piezoelectric transducer elements of the group and the second end of the first via electrically connected to the continuous ground.

8. The ultrasonic transducer system of claim 7, wherein second vias are provided for each of the M piezoelectric transducer elements of the N transducer groups.

9. The ultrasonic transducer system of claim 5, wherein the array is a curved array.

10. The ultrasonic transducer system of claim 5, wherein the array is a Tightly curved array.

* * * * *